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Mentor: David Martin
Cardiovascular Laboratory
Summer 2015 Abstract

Comparison of Venous Return Characteristics with Right Ventricular Mechanics during Cephalic Fluid Shift

This summer, I worked in the Cardiovascular Laboratory at the NASA Johnson Space center, which is tasked with discovering, evaluating, and developing countermeasures to the effects of microgravity on the cardiovascular system. There are several active areas of research, including the potential of vision impairment hypothesized to be caused by increased intracranial pressure secondary to the headward fluid shift caused by microgravity. The venous system and the right side of the heart, which have fallen in the shadow of arterial health concerning the left side of the heart, are indirectly tied to this microgravity risk. The interrelationship between venous return and right atrial and ventricular mechanics, specifically as it applies to positional or gravitational changes, is minimally represented in the literature. Therefore, there is a deficit in the understanding of venous pressures and right ventricular performance, especially under different loading conditions resulting from positional change.

For my summer internship project, I organized a pilot study to analyze the effects of a cephalic fluid shift on venous return and right ventricular mechanics to increase right ventricular and venous knowledge. To accomplish this pilot study, I wrote a testing protocol, obtained Institutional Review Board (IRB) approval, completed subject payment forms, lead testing sessions, and analyzed the data. This experiment used -20° head down tilt (20 HDT) as the ground based simulation for the fluid shift that occurs during spaceflight and compared it to data obtained from the seated and supine positions. Using echocardiography, data was collected for the right ventricle, hepatic vein, internal jugular vein, external jugular vein, and inferior vena cava. Additionally, non-invasive venous pressure measurements, similar to those soon to be done in-orbit, were collected. It was determined that the venous return from below the heard is increased during 20 HDT, which was supported by increased hepatic vein velocities, increased right ventricular inflow, and increased right ventricular strain at 20 HDT relative to seated values. Jugular veins in the neck undergo an increase in pressure and area, but no significant increase in flow, relative to seated values when a subject is tilted 20 HDT. Contrary to the initial expectations based on this jugular flow, there was no significant increase in central venous pressure, as evidenced by no change in Doppler indices for right arterial pressure or inferior vena cava diameter. It is suspected that these differences in pressure are due to the hydrostatic pressure indifference point shifting during tilt; there is a potential for a similar phenomenon with microgravity. This data will hopefully lead to a more in-depth understanding of the response of the body to microgravity and how those relate to the previously mentioned cardiovascular risk of fluid shift that is associated with spaceflight.

These results were presented in greater detail to the Cardiovascular Laboratory and the Space Life Science Summer Institute, which helped me prepare for future graduate school research presentations. This internship allowed me to apply and expand the anatomy, physiology, and mechanics information I learned during my undergraduate degree in Biomedical Engineering to the cardiovascular system with the unique zero gravity perspective. Additionally, I was able to develop skills with data analysis techniques involving speckle tracking for ventricular strain and Doppler waveforms for blood velocities. Additionally, I was able to expand upon my previous work in the Cardiovascular Laboratory by writing a literature review on a data analysis project I completed last summer. Ultimately, this internship and venous relationship comparison project provided me with a significant learning experience and additional skill sets, which are applicable to my goals of attaining a Ph.D. in biomedical engineering with a focus on tissue engineering and the cardiovascular system.

Acknowledgements: Thank you to the Minority University Research and Education Program, Grant Number NNX13AT16H for funding this project and the NASA Johnson Space Center Cardiovascular Lab for their guidance.

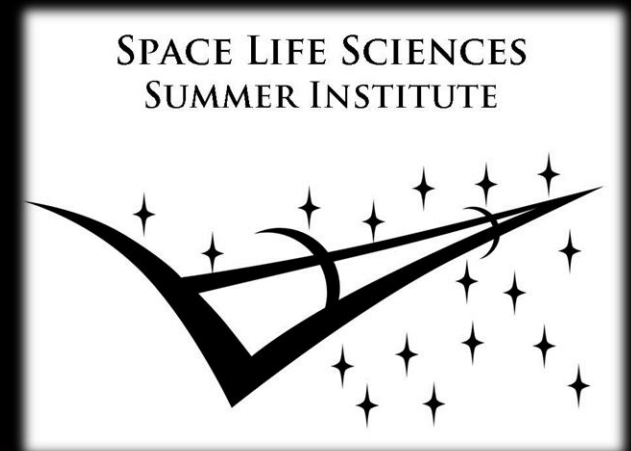


Comparison of Venous Return Characteristics with Right Ventricular Mechanics during Cephalic Fluid Shift

Morgan Elliott, Johns Hopkins University

Mentor: David Martin, Wyle Science, Technology, and Engineering Group

Cardiovascular Laboratory



Introduction

- Hometown: Chattanooga, TN
- Career Goals:
 - Ph.D. in Biomedical Engineering, specializing in Tissue Engineering
 - Product oriented research in industry or government
- Next Step: Attain Ph.D. at Johns Hopkins University
- Why NASA? Mission and deliverables oriented
- Internship Objectives:
 - Data Analysis
 - Publication



Background

Cardiovascular Lab

- Investigate how weightlessness affects the cardiovascular system to aid in the improvement of astronaut health, develop countermeasures, and potentially benefit other populations on Earth.
- Tests: head-down tilt bed rest (HDTBR), parabolic flight, hypovolemia models, and spaceflight

My Role

- Project 1: Define the frequency and pattern of mid-ventricular obstruction in the heart during high intensity exercise in a hypovolemic state
- Project 2: Compare venous return characteristics with right ventricular mechanics during postural changes

Methods

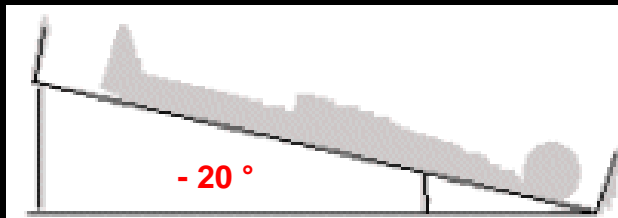
- Tilt angles: Seated, Supine, -20° Head down tilt (20 HDT)

HDT: Induce fluid shift similar to that in previous studies

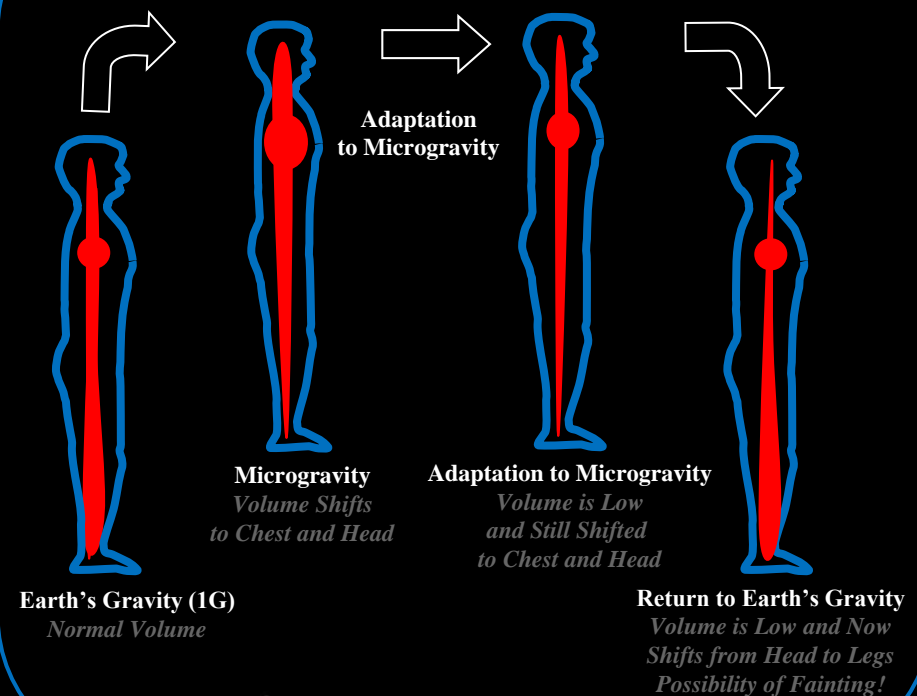
- 10 Subjects (8M, 2F, 178 ± 8 cm, 74 ± 13 kg, 33 ± 7 y)

- Scanned:

- Right Ventricle
- Hepatic Vein
- Internal Jugular Vein (IJV & EJV)
- External Jugular Vein (EJV)
- Inferior Vena Cava (IVC)



FLUID SHIFT IN WEIGHTLESSNESS



Jugular Vein

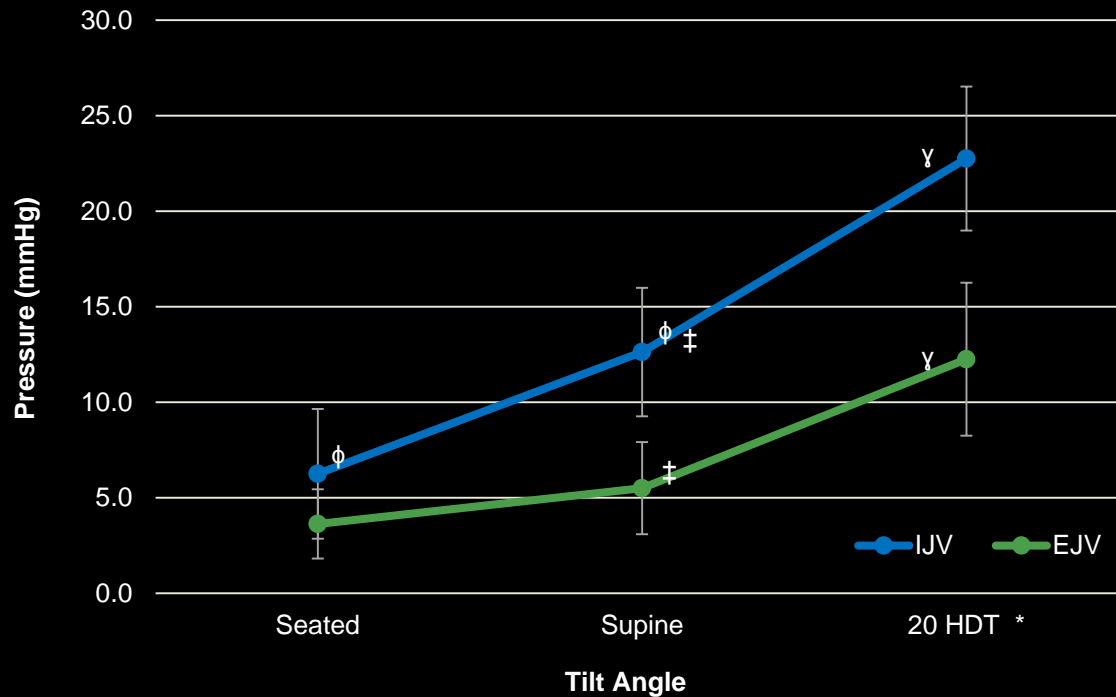
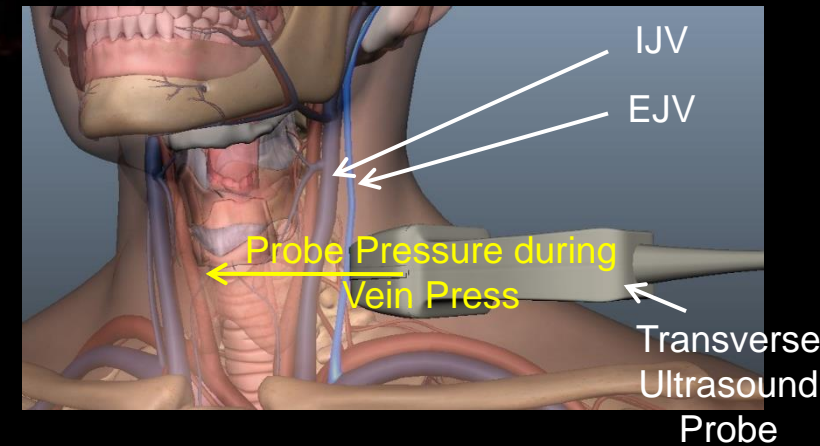
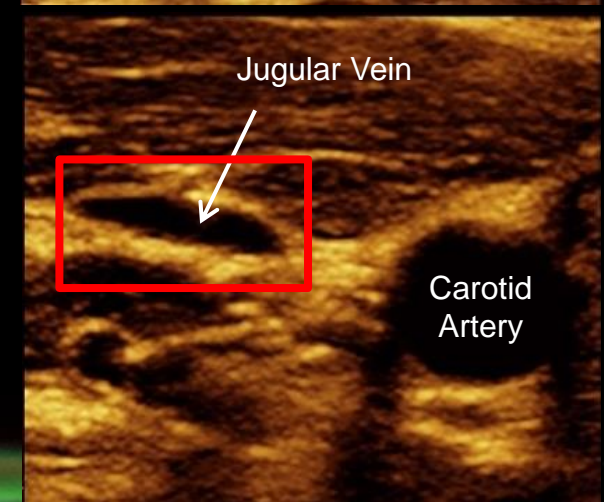
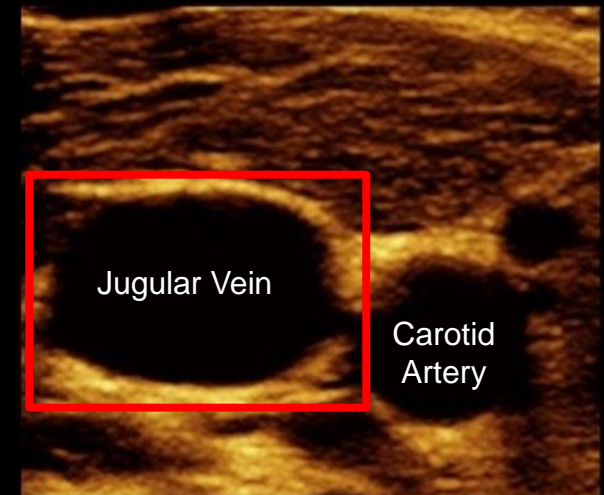


Figure 3. IJV pressures were significantly larger than the EJV pressures at supine and 20 HDT ($p < 0.05$) (\pm , γ). Pressures at 20 HDT were significantly larger than at seated and supine for both veins ($p < 0.01$) (*). For the IJV, pressures were significantly larger at supine than seated ($p \leq 0.05$) (ϕ). Pressures were measured during expiration and error bars are standard deviation ($n=6$ except $n=3$ at seated EJV).



Jugular Vein Cont.

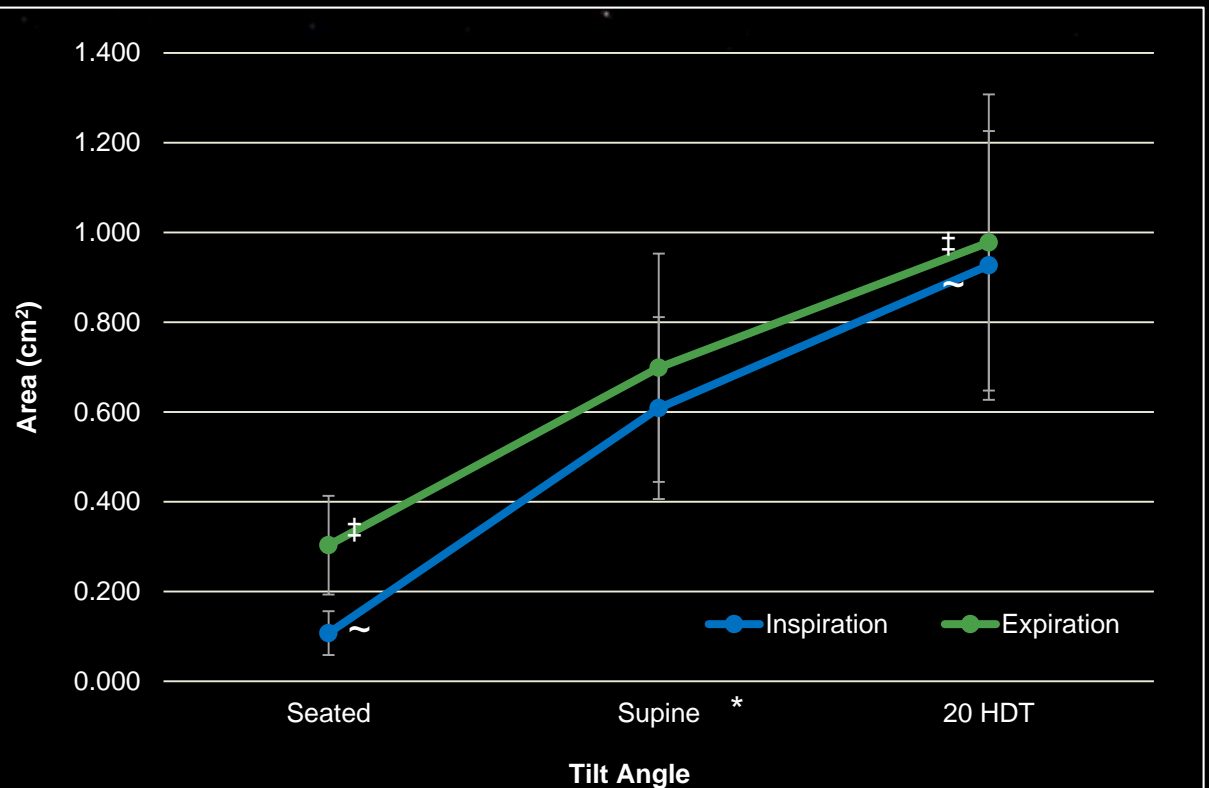
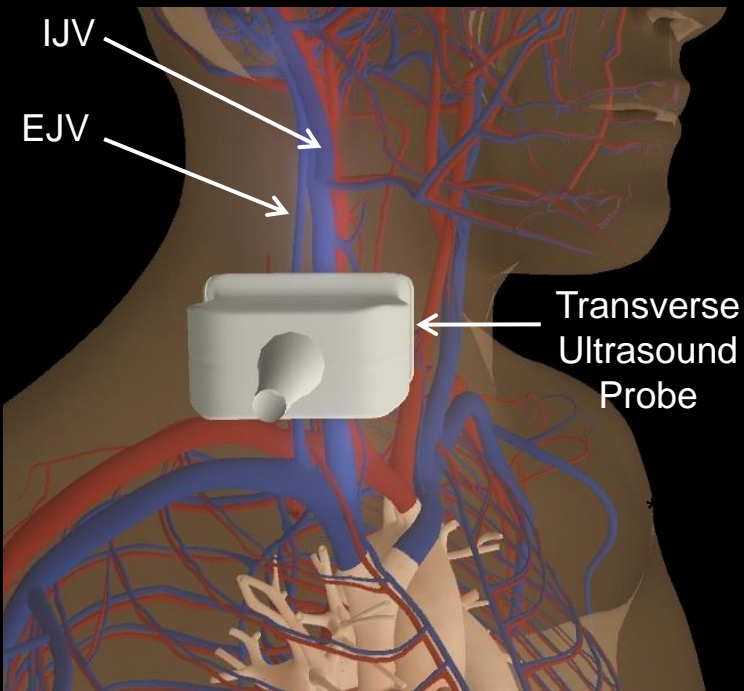


Figure 4. The IJV area significantly increases from seated to 20 HDT during inspiration ($p < 0.05$) (\ddagger). A similar trend occurs for expiration ($p < 0.06$) (\sim). Supine pressures are significantly greater than at seated and significantly less than at 20HDT ($p < 0.01$) (*). Error bars are standard deviation.

E Wave (Right Ventricular Inflow)

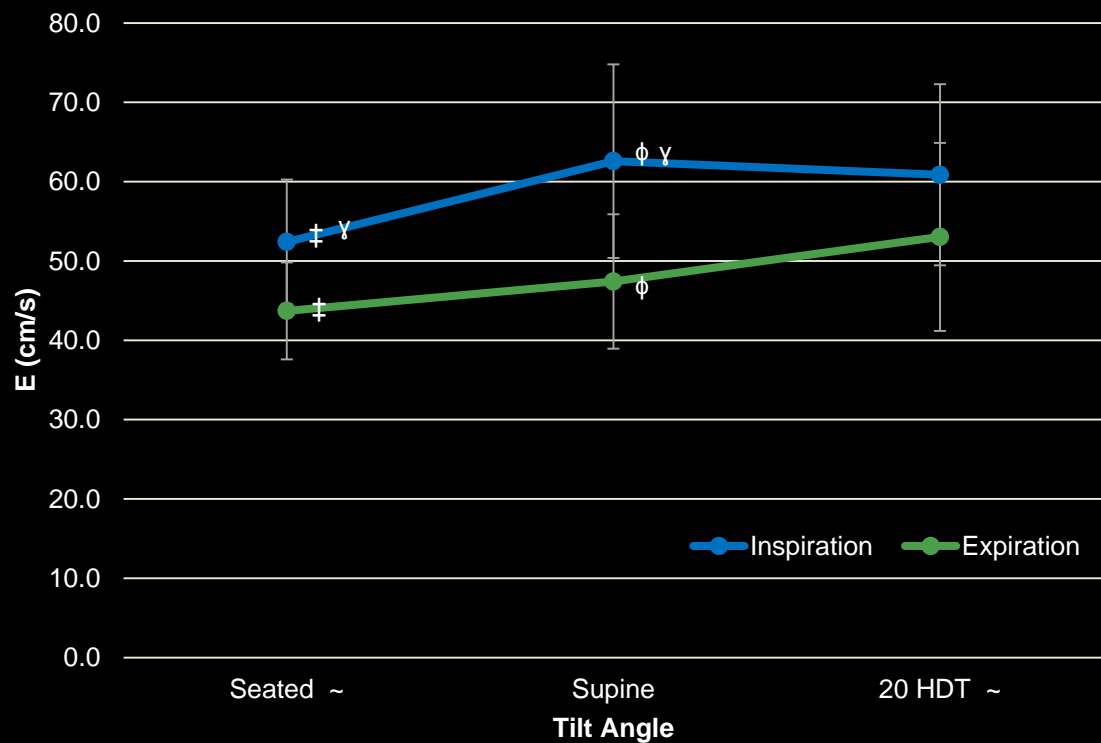
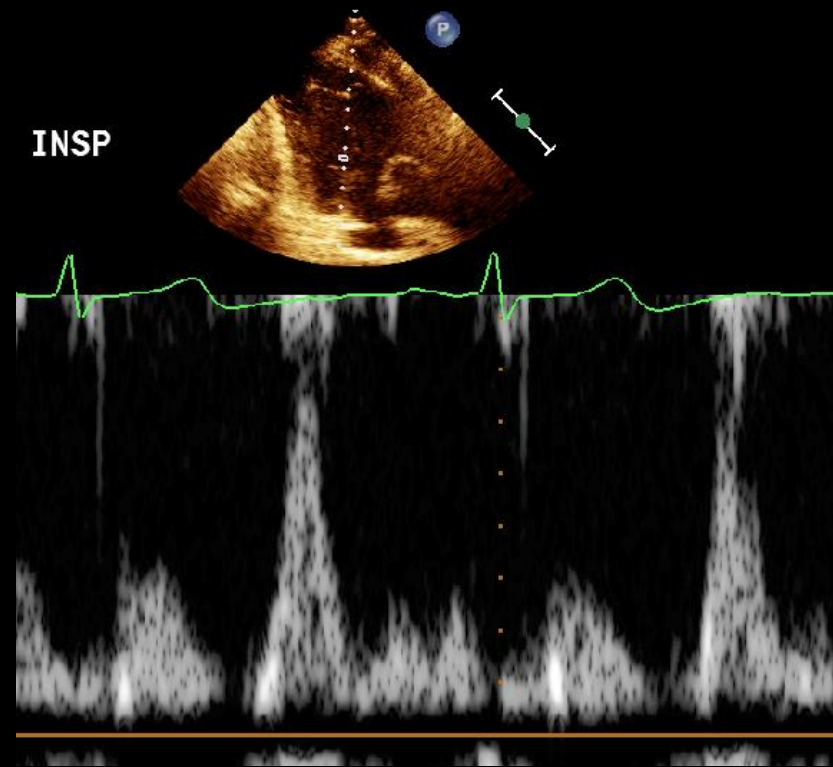
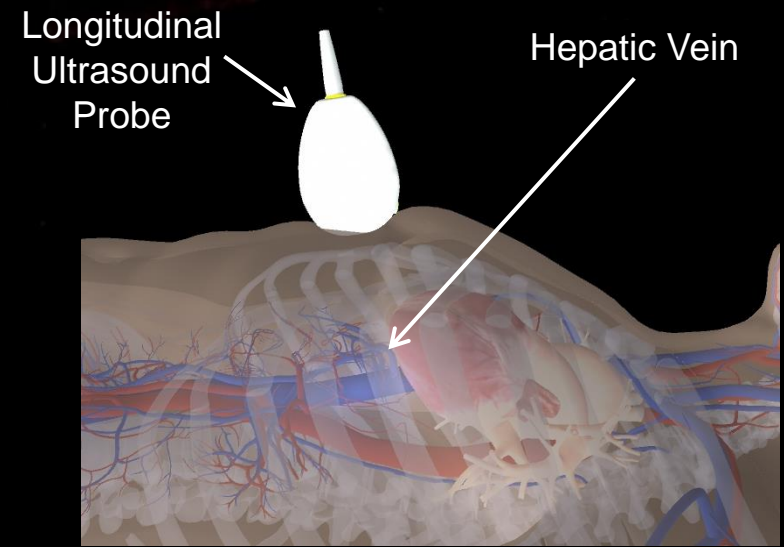
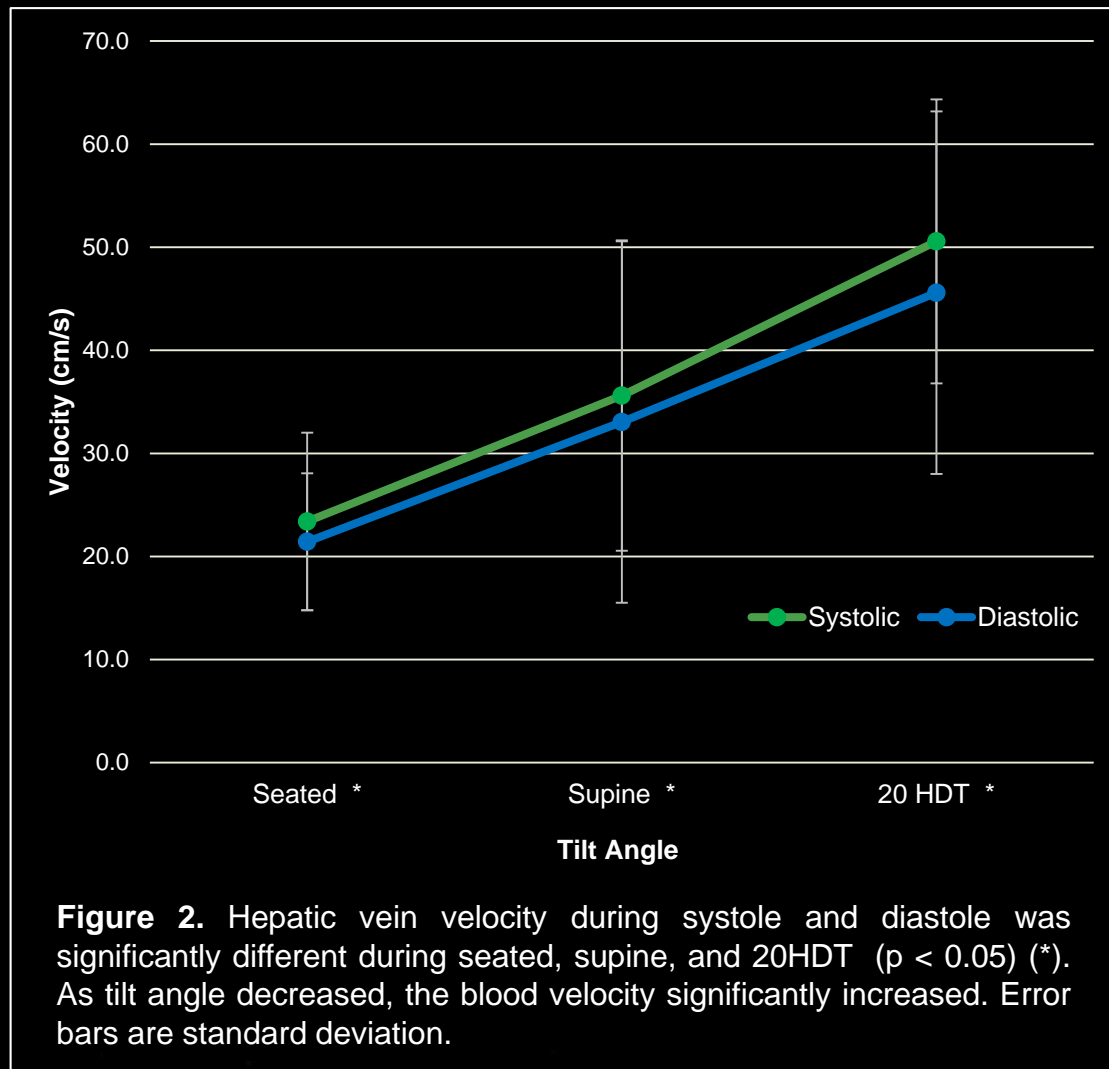


Figure 1. The E wave velocity was significantly larger during inspiration than at expiration while the subject was seated and supine ($p < 0.05$) (\ddagger , ϕ). During inspiration, the E wave was significantly larger at supine than at seated ($p \leq 0.05$) (γ). Additionally, there was significance and a trend (\sim) at expiration and inspiration, respectively, that the E wave was larger at 20 HDT than at seated. Error bars are standard deviation.

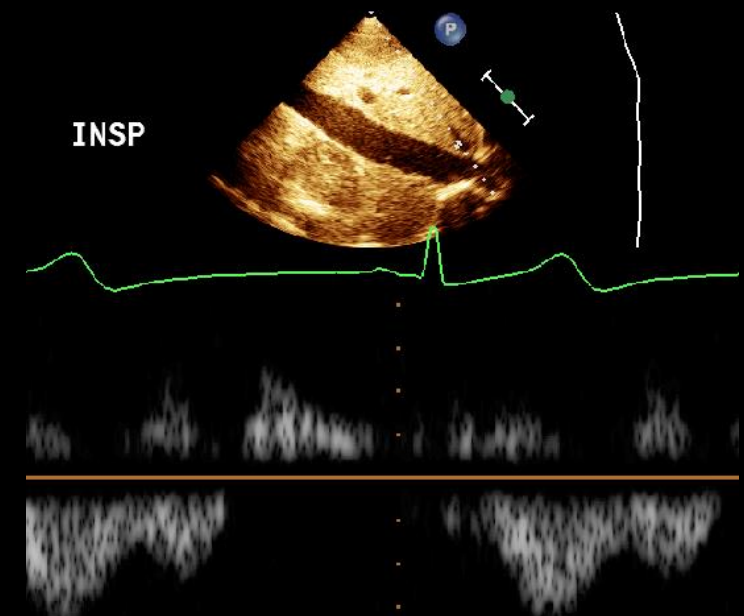
Velocity Waveform:



Hepatic Vein Velocities



Velocity Waveform:



Right Ventricular Global Longitudinal Strain

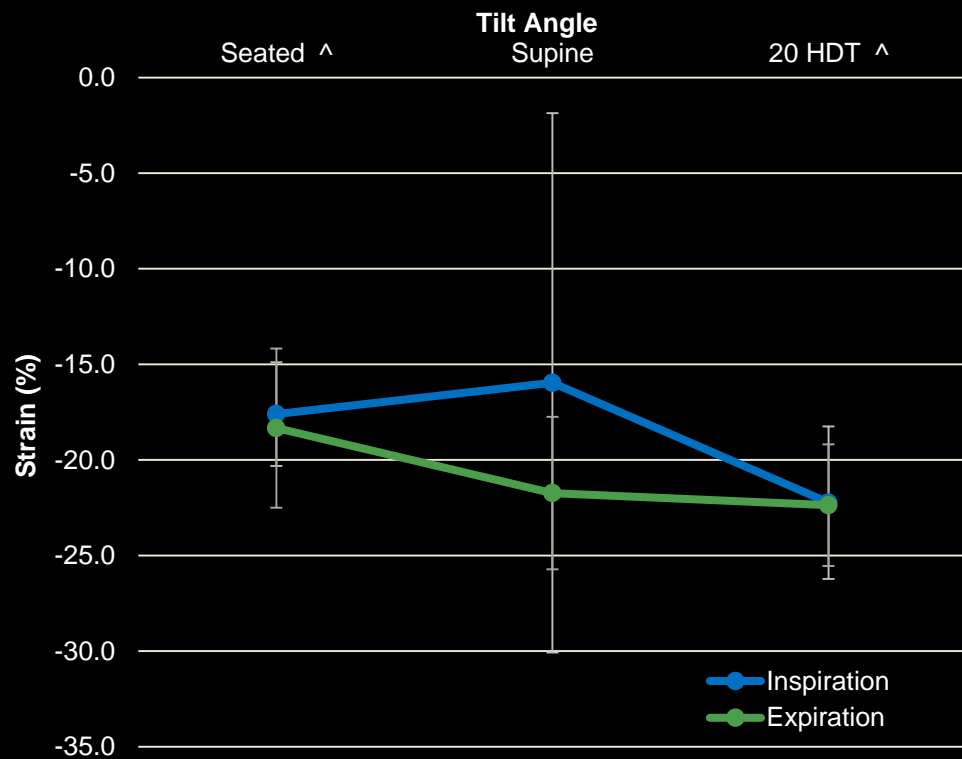
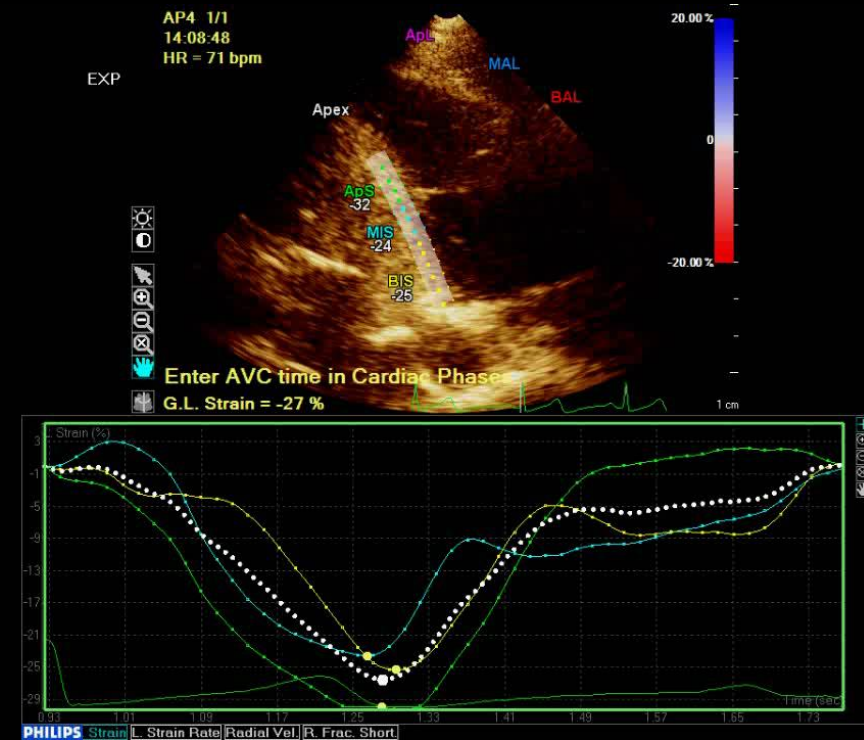


Figure 5. The negative strain indicates cardiac contraction. The heart is contracting significantly more, meaning the strain is more negative, at 20 HDT than at seated during both inspiration and expiration ($p < 0.05$) (^). Error bars are standard deviation.



Discussion

- Conclusions:

Increase in IJV pressure does not contradict intracranial pressure increase

A pressure gradient between the head to the heart is maintained

- IJV pressure, area, and flow
- Right atrial pressure, IVC diameter

Paradoxically, there is a increase in lower body venous return and RV strain during 20 HDT

- Hepatic vein velocity
- Right ventricular inflow

Internal jugular and right atrial pressure measurements were similar to previous reports in real or simulated microgravity

Discussion Cont.

- Limitations:

Small n value

Single, non-blinded analysis

Strain program limitations for right ventricular free wall

Image clarity due to artifact and interference

Difficult to obtain seated IJV

- Future Work:

Correlate Invasive pressure measurements with vein press

Examine relationships between assumed RA pressure and IVC diameter in spaceflight

References

Aubert, A.E., F. Beckers, and B. Verheyden, *Cardiovascular function and basics of physiology in microgravity*. Acta cardiologica, 2005. **60**(2): p. 129-151.

Hargens, A.R., R. Bhattacharya, and S.M. Schneider, *Space physiology VI: exercise, artificial gravity, and countermeasure development for prolonged space flight*. European journal of applied physiology, 2013. **113**(9): p. 2183-2192.

Mor-Avi, V. et al., *Current and Evolving Echocardiographic Techniques for the Quantitative Evaluation of Cardiac Mechanics: ASE/EAE Consensus Statement on Methodology and Indications*. Journal of the American Society of Echocardiography, 2011. 24: p. 277-313.

Norsk P., et. al. *Central venous pressure in humans during short periods of weightlessness*. Journal of Applied Physiology, 1987. 63(6): p. 2433-7.

Rudski L.G., et al. *Guidelines for the Echocardiographic Assessment of the Right Heart in Adults: A Report from the American Society of Echocardiography*. Journal of the American Society of Echocardiography, 2010. 23: p. 685-713.

Acknowledgements

- Minority University Research and Education Program, Grant Number NNX13AT16H for funding
- David Martin for answering all my questions and his guidance
- Dr. Jessica Scott, David Wilson, Rebecca Gonzales, Tim Matz, and Sydney Stein for testing assistance
- Dr. Stuart Lee, Dr. Mike Stenger, and Dr. Steve Platts for their guidance
- Cardiovascular lab staff for all their help and support
- Dr. Lauren Merkle for an amazing experience with SLSSI (x2)
- Missy Matthias and Melissa Corning for organizing the USRA intern program

